RESEARCH DEPARTMENT

VERTICALLY-POLARISED BAND III AERIAL
FOR SUTTON COLDFIELD

Report No. E-051

(1955/29)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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SUMMARY

This report describes the first stage in the development, using a small-scale model, of a vertically-polarised aerial for radiating two television programmes in Band III from Sutton Coldfield and similar high-power television stations. The aerial consists of 8 tiers of tangential batwing elements mounted on the existing slotted-cylinder Band II aerial. A further 8 tiers may be added subsequently to increase the gain.

1. INTRODUCTION.

A vertically-polarised aerial may be required for radiating Band III transmissions from the existing mast at Sutton Coldfield, and possibly at Holme Moss, Kirk o'Shotts and Wenvoe. This report describes the development of the aerial up to the stage at which a fully-engineered design can be prepared; further experimental work will be necessary to check the electrical performance of this design.

At the time when the design was undertaken, it was required to make provision for the radiation of two Band III programmes, with their associated sound signals, from the same aerial. The vision carrier frequencies were to be spaced 10, 15 or 20 Mc/s apart, the most probable allocation of channels being Nos. 8 and 12 (vision carrier frequencies 189·75 Mc/s and 209·75 Mc/s). Although it is now unlikely that there will be two Band III programmes, the report has been written with this end in view.

An intrinsic gain (ignoring all losses) of about 10 dB was originally specified (a change in this requirement, made after the completion of the experimental work, will be mentioned in Section 5). Whatever the form of the aerial it was clear that the vertical aperture would necessarily be at least 8 wavelengths (40 ft or 12 m), and it was therefore decided to employ 8 tiers spaced about one wavelength apart. Each half of the aerial (4 tiers) is to be connected to a separate feeder (this arrangement is referred to as a split aerial) in order to provide continuity of service in the event of failure of part of the aerial or of other equipment.

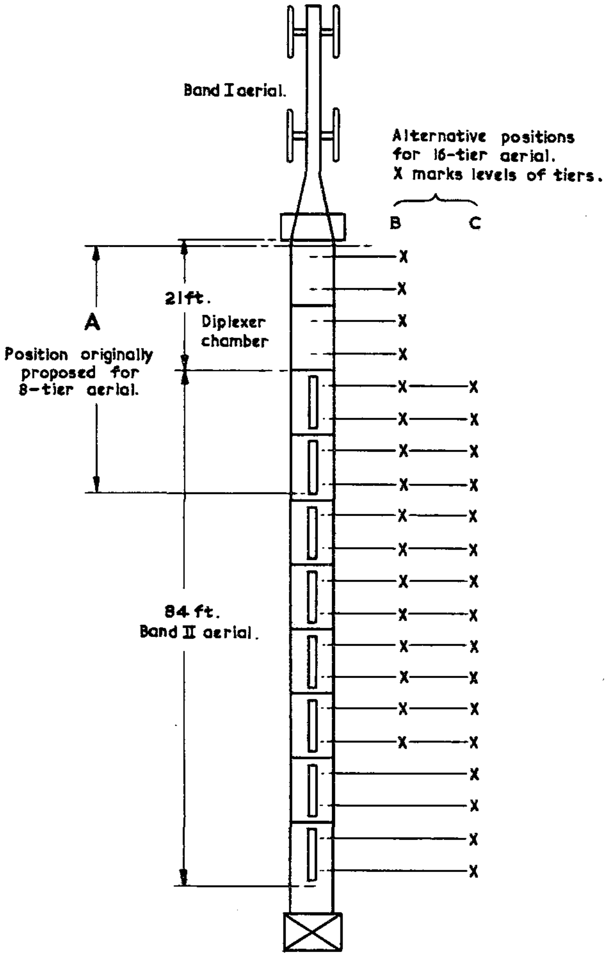


Fig. 1 - Proposed positions for Band III aerial

Propagation considerations made it desirable to mount the aerial at as great a height as possible. When mechanical considerations were also taken into account it was found that the new aerial could be mounted only on the existing cylindrical Band II aerial. The position originally selected, which is shown at A in Fig. 1, would entail interleaving the lower half of the Band III aerial with 2 tiers of the Band II aerial. It was appreciated that some impairment of the performance of the Band II aerial might result, but since only 2 tiers of it would be affected it was decided to accept any deterioration resulting. Since the Band III elements were to be vertically polarised it was assumed that the effect on their performance of the vertical slots in the cylinder would be negligible.

The horizontal radiation pattern (h.r.p.) is required to be as uniform as possible. In the case of an aerial for which the supporting mast is specially designed the maximum/minimum ratio is normally specified not to exceed 3 dB. In this case, however, it was realised that the difficulties inherent in mounting a new aerial on an existing mast, which was already stressed to the limit, would probably necessitate some relaxation of this specification.

The specification of the impedance characteristic of a television aerial is discussed in Research Department Report No. E-046[1]. It is required that this specification should be met in each of the two channels. Since the second channel might not be allotted until after transmission in the first channel had begun, it is desirable that after installation the aerial should be capable of adjustment to any two channels in Band III by means of convenient controls inside the Band II cylinder.

2. DESCRIPTION OF THE AERIAL.

The aerial will have 8 tiers each consisting of a ring of 4 tangential batwing elements oriented for vertical polarisation. Where the Band II and Band III aerials are interleaved, the batwing elements will be placed approximately mid-way between adjacent Band II slots of the same tier. Fig. 2 shows the small-scale model (scale factor 1/2·25) of a single tier used in the experiments.

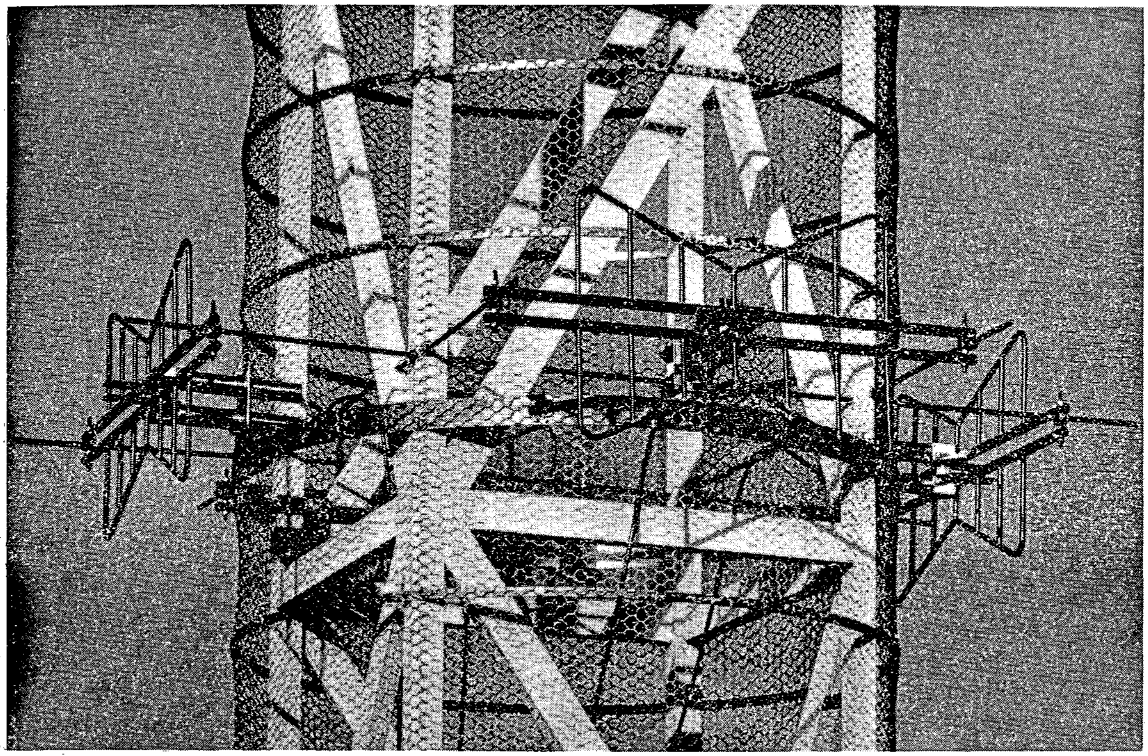


Fig. 2

The batwing element, which is the basis of the American R.C.A. Superturnstile aerial, may be regarded as a skeletonised slot. Its use as a separate radiating element supported by a mast of large cross-section was first proposed for the Norwich Band I television aerial[2]. In the present application it has two advantages. In the first place the bandwidth, as determined by the impedance characteristic, is very good. Secondly the radiation from each element corresponds to that originating from a pair of vertical dipoles spaced approximately one half-wavelength apart. Four tangential batwing elements would therefore be expected to give a more uniform horizontal radiation pattern than 4 vertical dipoles.

As shown in Fig. 2 the principal mechanical support for each element is provided by a pair of radial tubes at the centre, forming a short-circuited transmission line stub. These also act as a balun (Pawsey stub) driven by a 70-ohm transmission line in one of the tubes.

Each half of the batwing element is supported on one of the two horizontal tubes forming the edges of the slot. It is intended to bend these rods inwards at the ends and to attach them to the cylinder, in order to provide further mechanical support and to prevent the excitation of resonance in Band II by the horizontally-polarised fields of the Band II aerial. Since this feature of the element is not expected to influence its performance in Band III, no attempt was made to reproduce it in the model shown in Fig. 2. Instead, the ends of the element were supported by thin horizontal rods. For similar reasons no attempt was made to reproduce the Band II slots.

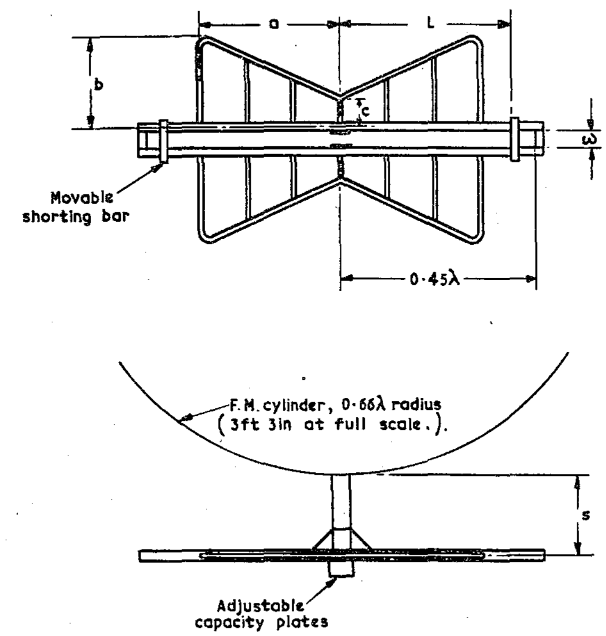


Fig. 3 - Plan and elevation of model batwing element

The model element is shown in more detail in Figs. 3 and 4. Where dimensions are quoted in wavelengths, the wavelength should be taken to be 4·92 ft or 150 cm (corresponding to 200 Mc/s) at full scale and 2·19 ft or 67 cm (corresponding to 450 Mc/s) in the model. Each of the tubes constituting the supporting stub ended in a rectangular box. A coaxial cable (Type PT1M), running inside one tube, had its outer conductor connected to this box, the inner being connected (by means of a vertical pillar) to the box at the end of the other tube. The 4 cables supplying the elements of the model aerial had equal lengths of about 10 ft (3 m). Adjustable capacity plates were provided at the centres of the elements.

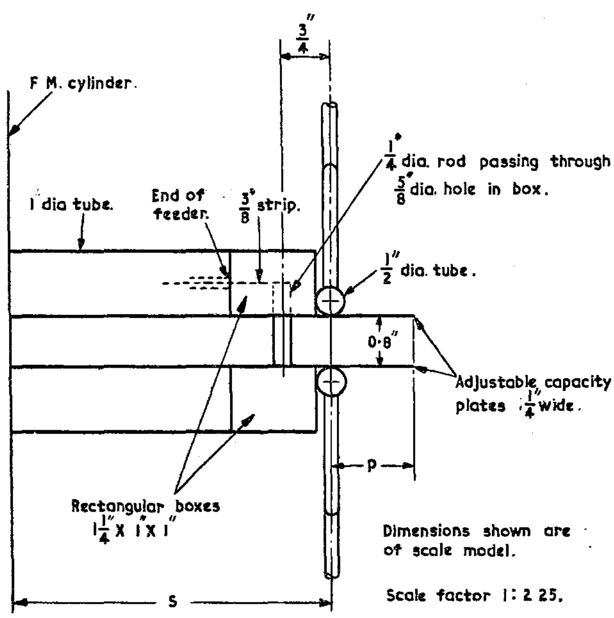


Fig. 4 - Mounting stubs for model batwing element

3. RADIATION PATTERNS.

3.1. Horizontal Radiation Pattern.

From calculation it appeared that the h.r.p. of a practicable arrangement of 4 batwing elements would have a maximum/minimum ratio of about 5 dB. It was therefore thought desirable in the final array to have the upper set of 4 tiers skewed by 45° relative to the lower set of 4 tiers. In other words if one set of tiers had elements facing North, South, East and West, the elements of the other set would face NE, SE, SW and NW, with the elements in the lower set approximately mid-way between the Band II slots. In this way a more uniform h.r.p. could be obtained, but it was appreciated that some loss of gain would result, since at any given bearing the contributions from the two halves of the aerial would not be equal and co-phased.

The effective h.r.p. of a skewed system was measured with the model of a single tier by using two receiving aerials spaced 45° and connected in parallel

through attenuators, as shown in Fig. 5. The distance of the two aerials from the axis of rotation of the model aerial, and the lengths of their cables, were carefully adjusted for equality. The h.r.p. obtained without skewing was measured by disconnecting one of the aerials from its attenuator, and doubling the measured field strength. The h.r.p.'s for the single and skewed systems were then correctly related in amplitude, so that the loss of gain due to skewing could be assessed.

The variation in measured field for both systems at various frequencies, and for different values of the parameter "a" (Fig. 3), is shown in Fig. 6. It will be observed that skewing considerably reduces the range of field-strength variation in the h.r.p., but that it does so mainly by reducing the maximum field, rather than by increasing the minimum field. It follows that there is little to be gained by skewing. Moreover it was found that if the halves of the aerial were to be fed from separate transmitters, as had been proposed, the phasing would be much more critical with skewing than without it. For these reasons it was decided not to adopt a skewed system, but to accept the most uniform h.r.p. obtainable without skewing. The h.r.p. of the complete aerial system will therefore be the same as that of a single tier.

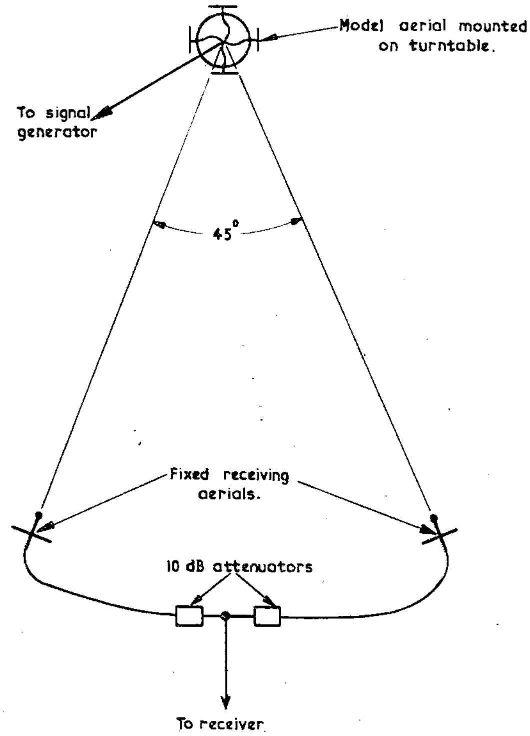


Fig. 5 - Method of measuring h.r.p. of a skewed aerial system

The h.r.p. varies with the length of the batwing elements (dimension "a" in Fig. 3) and with their spacing from the cylinder (dimension "s"). The admittance of the aerial is also affected by these parameters. The optimum h.r.p. together with a good admittance characteristic was obtained with $s = 0{\cdot}19\lambda$ and $a = 0{\cdot}33\lambda$; a typical pattern measured with this arrangement is shown in Fig. 7.

It will be noted that the h.r.p. has four-fold symmetry. A very uniform pattern, with eight-fold symmetry, would have been obtained if the 8 dipoles to which the 4 batwings are equivalent could have been equally spaced round the cylinder. Unfortunately the mast has too great a diameter for this to be possible. The values of "a" and "s" adopted gave the smallest maximum/minimum ratio possible with a practicable arrangement. If "a" is increased or "s" decreased deeper minima appear opposite the elements, while a reduction of element size or an increase in spacing gives a pattern with 8 maxima; in both cases the overall variation in the h.r.p. increases. A simultaneous increase or decrease of "a" and "s" leaves the pattern unchanged but degrades the admittance.

Although changes of element size and spacing have a marked effect on the shape of the h.r.p. they make very little difference to the mean gain of the aerial.

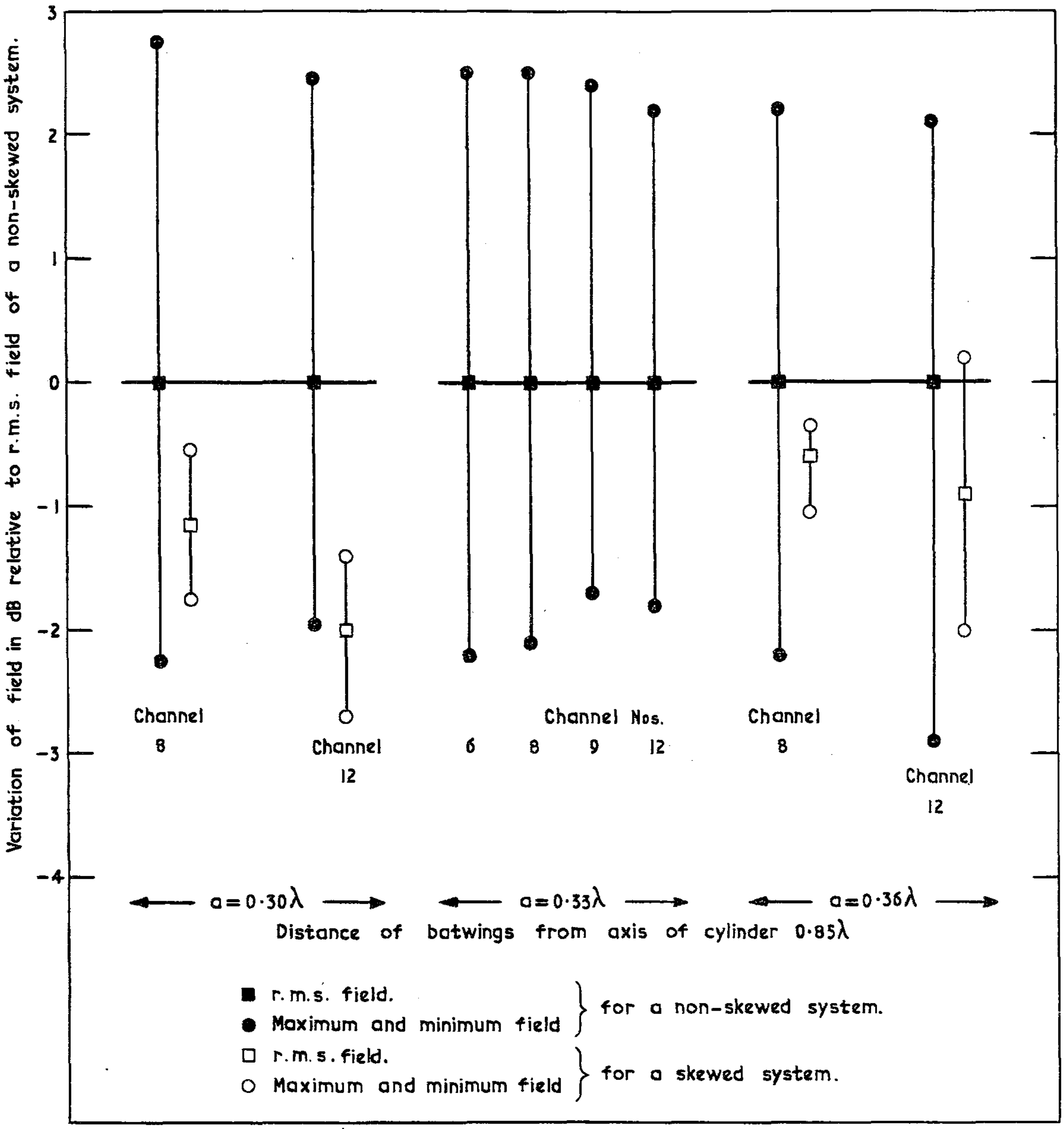


Fig. 6 - Field strength variation in horizontal pattern

It should also be noted that although the overall variation of the h.r.p. is large (4·3 dB in Fig. 7) the maxima are relatively narrow, so that the minimum field is only 1·8 dB below the r.m.s. value. It is this feature of the h.r.p. which is important. (We may compare the more usual type of h.r.p. in which the field strength varies sinusoidally. A minimum field 1·8 dB below the r.m.s. value corresponds to a maximum/minimum ratio of only 3·1 dB.) Thus the loss of field in the direction of the minimum due to the non-uniformity of the h.r.p. is about the same as that of most types of aerials having a maximum/minimum ratio of 3 dB.

3.2. Vertical Radiation Pattern.

The vertical radiation pattern of a single tier was measured in two planes, one passing through the centres of opposite elements, and the other mid-way between elements. The results were compared with theoretical patterns obtained by treating each batwing element as a pair of vertical dipoles. The agreement was sufficiently close to enable the gain of an 8-tier array to be deduced from the theoretical patterns.

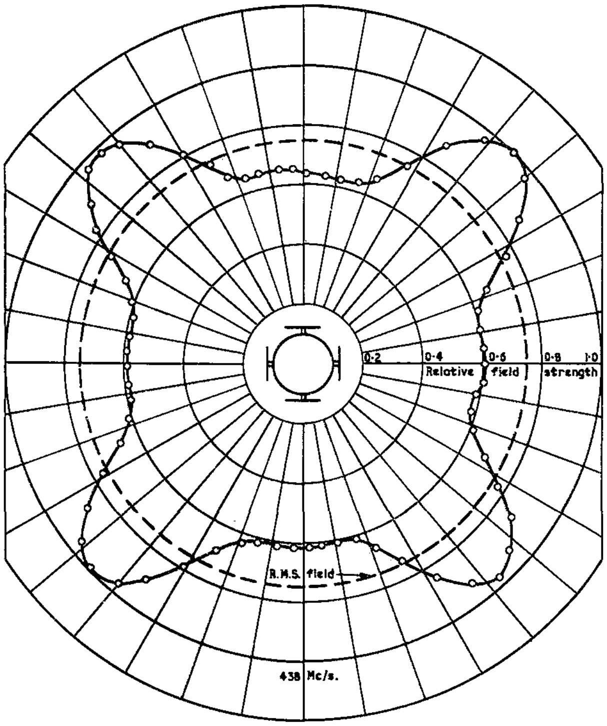


Fig. 7 - Measured h.r.p.

With an inter-tier spacing of 4 ft 7 in. or 140 cm (0·93λ at 200 Mc/s) the gain of 8 tiers was found to be 9·4 dB at 190 Mc/s (channel 8), 9·6 dB at 200 Mc/s and 9·6 dB at 210 Mc/s (channel 12). The effective gain, taking account of losses, will be considered in Section 6.

4. ADMITTANCE.

4.1. Requirements.

The admittance presented to the main feeder by the aerial system must satisfy the specification laid down in Research Department Report No. E-046[1] in each of two Band III channels, but it is not proposed to attempt to match each batwing element to this degree of accuracy. Instead, it is intended to match the elements as well as possible over the whole of Band III (174 Mc/s to 216 Mc/s). Then, by means of two suitably spaced controls inserted in the feeders, the main feeder will be matched exactly (within the limits of experimental error) at the two vision carrier frequencies. Each of these controls will introduce a reflection coefficient of variable magnitude and phase: a possible design could consist of a short length of line of high characteristic impedance with two adjustable shunt capacitors spaced one eighth of a wavelength apart. One of the controls should be placed as close to the elements as possible, i.e. at the top of the main feeder supplying one half of the aerial. The other control should be placed lower in the main feeder, at a distance depending on the frequency separation between the two channels. For a separation of 20 Mc/s the distance between the controls should be about 12 ft or 3·75 m (one quarter-wavelength at 20 Mc/s).

This method of matching has the advantage that the final adjustment can be carried out inside the mast. Furthermore no adjustment to the elements would be necessary in the event of a change of channel allocation.

It would be possible to match the aerial at the vision carrier frequencies by means of the two controls whatever the impedance of the elements, but the resulting reflection coefficient at the vision sideband frequencies might then be outside the limits specified in Research Department Report No. E-046. It was found by calculation, assuming typical aerial admittance characteristics, a feeder loss of 1·3 dB, and a channel separation of 20 Mc/s, that the specification can be met without difficulty provided the standing-wave ratio (s.w.r.) of the elements exceeds 0·8 over the band. Thus the object of the admittance measurements on the model was to match the elements to a standing-wave ratio greater than 0·8 over the frequency range 400-500 Mc/s. Each of the two admittance controls provided in the feeder system should be capable of introducing a reflection coefficient of any phase and any magnitude up to 0·1.

4.2. Method of Measurement.

Preliminary measurements of the admittance were performed on a single batwing element, the admittance of which had been found to differ only slightly from that of a tier of four elements. The element was connected through a 10 ft (3 m) length of PT1M cable to a General Radio Admittance Meter, modified for operation with 70-ohm cable. The final measurements were performed on four elements, a double quarter-wave transformer being inserted between the cables and the admittance meter. The measuring system was calibrated by connecting four long terminated cables to the transformer and noting the admittance presented to the meter when they were well-matched. The cables were then cut to the required length and their electrical length and loss determined in a separate experiment. All the admittance measurements are normalised to the characteristic admittance of PT1M cable (13·8 ± 0·3 mmho).

4.3. Admittance of One Tier.

The initial series of admittance measurements was performed on batwing elements similar in shape to those used in the Superturnstile aerial, but slightly smaller ($a = 0{\cdot}30\lambda$) as these had been found to have a better bandwidth in a similar application. When the proposal to skew the two halves of the aerial by 45° was abandoned it was found necessary either to increase the size of the elements or to reduce their spacing from the mast in order to obtain an acceptable h.r.p. The latter alternative gave a very poor admittance characteristic and it was therefore decided to increase all the element dimensions by 20%. The effect of simultaneously reducing dimensions "b" and "c" by equal amounts was then investigated, and it was found that an acceptable bandwidth was obtained when "b" had the same value as before the all-round increase in size. Meanwhile, h.r.p. measurements indicated that the optimum value of "a" lay mid-way between those already tried. Intermediate elements were therefore adopted, dimension "b" remaining unchanged. The dimensions finally adopted are summarised in Table 1.

4.4. Mutual Admittance.

An acceptable admittance characteristic for one tier of elements having been obtained, the mutual admittance between two adjacent tiers was measured by placing the cylinder at the centre of a sheet of galvanised wire netting 8 wavelengths square. The four elements were mounted at a height above the sheet such that their images formed an adjacent tier. Thus the admittance measured was that of two adjacent tiers.

An alternative measurement of the mutual admittance was performed by arranging the four elements in two half-tiers. Each half-tier comprised two elements mounted at the same level on adjacent faces of the mast, and the two half-tiers were vertically above each other. It was assumed that the admittance measured in this way would not differ greatly from that of two complete tiers, because the mutual admittance between elements of the same tier is small. The mutual admittance between adjacent tiers was readily determined by reversing the phase of one tier; the difference between the two measurements was then equal to twice the mutual admittance. Results obtained by the two methods were in close agreement.

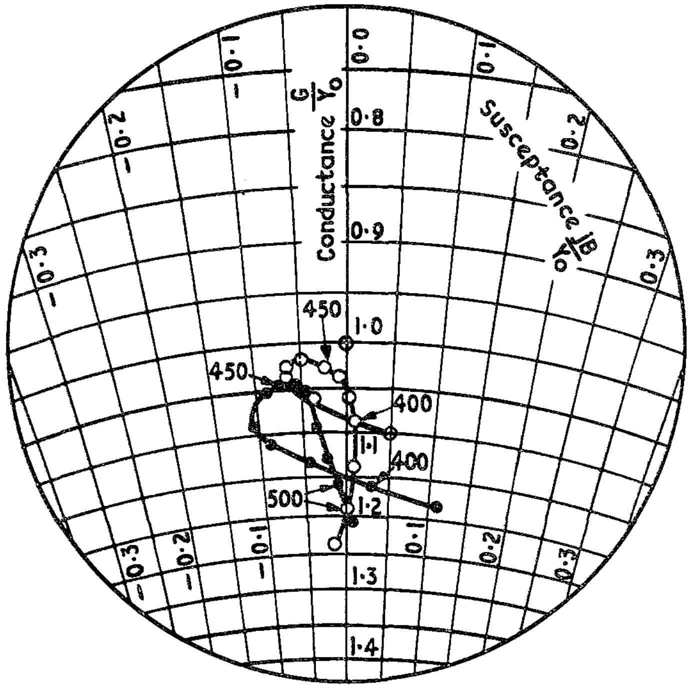


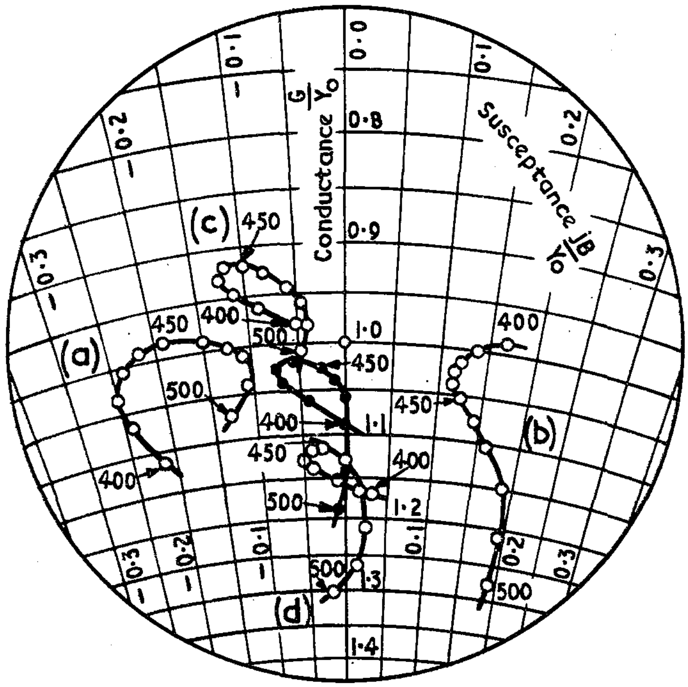
Fig. 8 - Admittance loci of interleaved Band III aerial

If the admittance of of two adjacent tiers energised in phase is Y_{S2} and the mutual admittance between adjacent tiers is Y_M, then the mean admittance of an element of an 8-tier aerial is $Y_{S2} + 0{\cdot}75Y_M$ if the mutual admittance between tiers that are not adjacent is neglected. The admittance of an 8-tier aerial was estimated on this basis and adjustments and measurements on the two half-tiers were performed until the optimum estimated 8-tier admittance was obtained.

4.5. Method of Adjusting Elements.

The admittance of the two half-tiers is shown in Fig. 8 together with the estimated admittance for 8 tiers. If the centre of the loop formed by the admittance curve is moved to the centre of the admittance diagram, the s.w.r. over the range 400-500 Mc/s is then greater than 0·9: as stated in Section 4·1, the minimum permissible s.w.r. is 0·8.

Fig. 9 shows the effects of the adjustments which were provided to enable the admittance characteristic to be centred. Increase of the capacity at the centres of the elements increases the input conductance; this capacity appears to be effectively one eighth-wavelength from the end of the measuring cable owing to inductance of the feed-point connection. The input susceptance may be controlled by changing the slot length, but, as shown in curves (a) and (b), the bandwidth is degraded. It is therefore recommended that the susceptance should be adjusted as well as possible by introducing fixed capacitance at the end of the coaxial feeder. Slot length may then be used as a fine control.



Central curve: admittance of two half-tiers spaced 0·93 λ.
(a). Slots lengthened by 5 %.
(b). Slots shortened by 5 %.
(c). Capacity at centres of elements reduced by 60 %.
(d). Capacity at centres of elements increased by 40 %.

Numbers denote model frequencies in Mc/s.

Fig. 9 - Effect of adjustments on admittance of two half-tiers of interleaved Band III aerial

The final dimensions of the elements in wavelengths are summarised in Table 1, together with the dimensions at full scale.

5. PROPOSAL TO INCREASE THE NUMBER OF TIERS TO 16.

After the completion of the preliminary investigation described in Sections 1–4 it was decided to make it possible to increase the gain by 3 dB after the aerial had been taken into service. This would be done by installing an additional 8 tiers below the first 8 tiers. The main feeders would then be re-arranged to supply 8 tiers each, instead of 4 tiers as in the original arrangement.

A 16-tier Band III aerial would require to be interleaved with at least 6 tiers of the Band II aerial, even if the diplexer sections were used, so that its effect on the performance of the Band II aerial could not be overlooked. It was clear that this problem would be simplified if all the tiers of the Band II aerial were affected equally, and it was therefore decided to increase the inter-tier spacing

TABLE 1

Distance of batwing centres from axis of cylinder		$0{\cdot}85\lambda$	(4 ft $2\frac{1}{4}$ in. = 128 cm)
Distance of batwing centres from face of cylinder	s =	$0{\cdot}19\lambda$	($11\frac{1}{4}$ in. = 28·5 cm)
Dimensions of batwing element	a =	$0{\cdot}33\lambda$	(1 ft $7\frac{1}{2}$ in. = 49·5 cm)
	b =	$0{\cdot}22\lambda$	(1 ft 1 in. = 33 cm)
	c =	$0{\cdot}062\lambda$	($3\frac{5}{8}$ in. = 9·2 cm)
Diameter of tubes forming slot		$0{\cdot}019\lambda$	($1\frac{1}{8}$ in. = 2·9 cm)
Distance between centres of tubes forming slot		$0{\cdot}049\lambda$	($2\frac{7}{8}$ in. = 7·3 cm)
Slot half-length for admittance shown in Fig. 9	L =	$0{\cdot}40\lambda$	(1 ft $11\frac{1}{2}$ in. = 60 cm)
Maximum possible slot length		$0{\cdot}45\lambda$	(2 ft $2\frac{1}{2}$ in. = 67 cm)
Slot width	w =	$0{\cdot}030\lambda$	($1\frac{3}{4}$ in. = 4·5 cm)
Width of capacity plates (model)		$0{\cdot}048\lambda$	
Width of capacity plates (as specified to P.I.D.)		$0{\cdot}051\lambda$	(3 in. = 7·6 cm)
Extension of capacity plates for admittance shown in Fig. 9	p =	$0{\cdot}055\lambda$	($3\frac{1}{4}$ in. = 8·3 cm)
Diameter of tubes forming mounting stub		$0{\cdot}038\lambda$	($2\frac{1}{4}$ in. = 5·7 cm)
Distance between centres of tubes forming mounting stub		$0{\cdot}068\lambda$	(4 in. = 10 cm)

of the Band III aerial from 4 ft 7 in. (140 cm) to 5 ft 3 in. (160 cm), ($0{\cdot}93\lambda$ to $1{\cdot}06\lambda$ at 200 Mc/s), exactly one-half that of the Band II aerial. Two tiers of the former would then be mounted symmetrically on one tier of the latter. Calculation has shown that at 200 Mc/s the intrinsic gain of 8 tiers would be reduced by 0·1 dB by this increase in spacing. The intrinsic gain at 200 Mc/s would therefore be 9·5 dB for 8 tiers and 12·5 dB for 16 tiers. The change in inter-tier spacing will also result in a change in input admittance, owing to the change in mutual admittance between tiers. This change will, however, be small, and it is not proposed to take it into account until a fully-engineered design has been prepared (see Section 7).

An investigation into the effect on the performance of the Band II aerial of interleaving with the Band III aerial is described fully in Research Department Report No. E-053[3]: briefly the conclusions were as follows.

i. The maximum/minimum ratio in the h.r.p. of the Band II aerial will increase from 0·6 dB to 1·6 dB.

ii. The change in the impedance of the Band II aerial due to the presence of the batwing elements could be taken up by the means of adjustment provided. It would not degrade the bandwidth.

iii. The change in the gain of the Band II aerial will be negligible provided that all 8 tiers are affected equally.

In view of (iii) above, it is desirable that the 16-tier Band III aerial should be interleaved completely with the Band II aerial, as shown at C in Fig. 1. Initially, when only the upper 8 tiers of the Band III aerial have been installed, any loss of gain in Band II may be avoided by suitably phasing the feeds to the halves of the Band II aerial. The alternative position of the Band III aerial shown at B in Fig. 1 would be less satisfactory, even though the greater height would give a field

greater by 0·25 dB, but it could be accepted if necessitated by mechanical considerations. The loss of gain in Band II due to the presence of the Band III aerial in position B would probably not exceed 1 dB.

If all tiers of the Band III aerial are energised equally and in phase, the vertical radiation pattern will exhibit sidelobes separated from each other and from the main lobe by deep minima, which will result in circular zones of comparatively low field strength in the immediate neighbourhood of the aerial. Although the field strength in these zones of minimum field will always be adequate in practice, there will be considerable differences between the levels of the two transmissions, and the signals may be distorted and variable. The radius of the outermost of these zones is about 1 mile (1·6 Km) for an 8-tier aerial and 2 miles (3·2 Km) for a 16-tier aerial. At Sutton Coldfield the number of viewers affected would be small in the former case, and some degradation of their service could be accepted. If 16 tiers were to be installed a much larger number of viewers would be affected, and it would be necessary to take steps to fill in the minima of the vertical radiation pattern, a process known as gap filling. The best method of gap filling has not yet been considered, but it may be assumed that a loss of gain of about 0·5 dB would result. It follows that the improvement in effective aerial gain resulting from the addition of the second group of 8 tiers would be only 2·5 dB. The improvement in field strength at the fringe of the service area would be only 2·25 dB, if account is taken of the fact that the centre of the aerial would be lowered by 20 ft (6 m).

6. EFFECTIVE GAIN.

The effective gain of the aerial system is calculated in Table 2 below for a frequency of 200 Mc/s. In accordance with the decision referred to in Section 5, an inter-tier spacing of 5 ft 3 in. (160 cm) has been assumed.

TABLE 2

	8 tiers	16 tiers
Intrinsic gain, ignoring gap filling and losses	9·5 dB	12·5 dB
Deduct loss of gain in gap filling	–	0·5 dB
Leaving	9·5 dB	12·0 dB
Deduct loss in distribution feeders	0·1 dB	0·1 dB
Deduct loss due to accidental misphasing etc.	0·2 dB	0·2 dB
Leaving aerial net gain	9·2 dB	11·7 dB
Deduct loss in 800 ft (245 m) of 5 in. (12·7 cm) feeder*	1·3 dB	1·3 dB
Deduct loss in filters and miscellaneous losses	0·2 dB	0·2 dB
Leaving effective gain	7·7 dB	10·2 dB
i.e. Power ratio	5·9	10·5
*At Holme Moss 3¼ in. (8·3 cm) feeder will be used;		
The loss for 850 ft (260 m) is	2·0 dB	2·0 dB
The effective gain is	7·0 dB	9·5 dB
i.e. Power ratio	5·0	8·9

7. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK.

The development has been taken to the point at which a fully-engineered design for the aerial and feeder system can be prepared. It is considered that admittance measurements should then be made on four prototype elements assembled in two half-tiers. It is essential that these elements should include the termination of the coaxial feeder at the feed-point, with any supporting insulator, since this is the feature that is likely to depart most widely from the model. After any necessary modifications have been made it is recommended that further measurements should be made on 8 elements assembled in two complete tiers.

The object should be to obtain an admittance characteristic which, after allowance has been made for mutual admittance, gives the best match over the whole of Band III. It should be possible, by adjusting slot length and the capacitance at the centre, to obtain a range of adjustment approximately corresponding to that shown in Fig. 9, but it is hoped that this adjustment would not prove necessary after installation.

It would be possible to do the work referred to above with the aid of small-scale model elements, but it is doubtful whether any advantage would be gained. In fact it is understood that P.I.D. propose to use a full-scale single-tier prototype Band II aerial, which is already in existence, as a support for full scale prototype Band III elements.

8. REFERENCES.

1. "Specification of the Impedance Characteristics of Television Transmitting Aerial Systems", Research Department Report No. E-046, Serial No. 1953/18, July, 1953.

2. "Horizontally-Polarised Directional Band I Aerial for the Norwich Medium-Power Television Station", Research Department Technical Memorandum No. E-1032.

3. "The Effect of an Interleaved Band III Aerial on the Performance of a Band II Slot Aerial", Research Department Report No. E-053.

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